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PENTOBARBITAL AND d-*AMPHETAMINE EFFECTS ON CONCURRENT PERFORMANCES*

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The effects of pentobarbital and *d*-amphetamine were studied in pigeons responding under several concurrent fixed-ratio variable-interval and concurrent fixed-ratio fixed-interval schedules of food presentation. Drug effects were compared with different fixed ratios, fixed and variable intervals, changeover delays, and with the schedules operating singly. Doses of *d*-amphetamine that increased or did not affect responding under the interval schedules decreased responding under the fixed-ratio schedule, whereas doses of pentobarbital that increased responding under the fixed-ratio schedule decreased or eliminated responding under the interval schedules. These effects depended both on the schedule of food delivery and the parameters of schedules arranged concurrently. Pentobarbital increased responding under the fixed-ratio schedule with 4-minute and 10-minute interval schedules arranged concurrently, but not with 1.5-minute schedules. *d*-Amphetamine decreased concurrent ratio and interval responding with the 1.5-minute interval schedules, but either increased or did not affect responding with the longer intervals. Changes in the parameter of one schedule altered responding controlled by that schedule and also other concurrent performances. As a consequence, the effects of drugs on each behavior were altered.

Key words: pentobarbital *d*-amphetamine, concurrent schedules, fixed ratio, variable interval, fixed interval, changeover delay, pigeons

There is ample evidence that the effects of drugs are related to the predrug frequency and temporal distribution of responses (Dews, 1958*b;* Kelleher and Morse, 1968; Sanger and Blackman, 1976*a*). Moreover, the effects of drugs on responding in one component of a compound schedule are also determined by characteristics of responding in other components (McKearney and Barrett, 1975). The importance of these other behaviors in determining the effects of drugs has been studied most often with multiple schedules, in which different schedules of reinforcement are present sequentially. Much less is known about behaviors under the control of concurrently available schedules. With concurrent schedules, two or more individual schedules operate simultaneously and responding under each schedule can occur at any time. Thus, with concurrent schedules, interactions between different behaviors can maximally influence the effects of drugs.

The effects of amphetamine and pentobarbital on responding under ratio and interval schedules, when arranged as single or multiple schedules, are well documented (Dews, 1955, 1958*b;* Kelleher and Morse, 1968; Sanger and Blackman, 1976*b*). Generally, doses of pentobarbital that increase the high rates of responding ordinarily maintained by fixed-ratio schedules decrease the lower rates of responding ordinarily maintained by interval schedules. Amphetamines, on the other hand, increase low rates maintained by interval schedules but decrease high rates of responding maintained by fixed-ratio schedules.

The few studies of drug effects on concurrent responding obtained findings similar to those with multiple and single schedules. With each schedule, the event used to maintain responding appears to be less important in determining drug effects than the schedule-controlled response rates and patterns maintained by those

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events. Similar patterns and rates of responding maintained by different events are affected similarly by a variety of drugs (Cook and Catania, 1964; Hearst, 1961; Kelleher and Morse, 1964). On the other hand, when different events maintain different patterns or rates of responding, drug effects are different (Cook and Catania, 1964; Cook and Kelleher, 1962). For example, Cook and Catania (1964) studied a concurrent shock-postponement fixed-ratio food presentation schedule. *d*-Amphetamine selectively increased low rates under the shock-postponement schedule and decreased high rates under the fixed-ratio schedule. But such differential effects of drug could be attributed either to the different schedules or to the different events maintaining responding on the schedules. Todorov, Gorayeb, Correa, and Graeff (1972) studied the effects of *d*-amphetamine on concurrent variable-interval variable-interval schedules of food presentation, with different parameters arranged in each schedule. Response patterns were similar but moderately different local response rates were maintained by each schedule. *d*-Amphetamine reduced responding under each schedule in a similar manner. Thus, if response patterns and the events maintaining responding are similar, drug effects are also likely to be similar.

The present experiments extended the study of the effects of drugs on concurrent performances. Fixed-ratio schedules were paired with either fixed-interval or variable-interval schedules. Responding under each schedule was maintained by food presentation, but different response rates and patterns were controlled by the different schedules. In addition, absolute and relative response rates under each schedule were varied by changing the size of the ratio requirement and the duration of the fixed or variable interval. Schedule parameters were selected on the basis of previous experiments (Bacotti, 1977), so that drug effects could be assessed over a broad range of response rates under each schedule, *e.g.*, between exclusive responding under the ratio schedules and exclusive responding under the interval schedules.

The effects of *d*-amphetamine and pentobarbital under these conditions were generally similar to their effects on ratio and interval schedules arranged as single or multiple schedules. However, changing parameters of the concurrent schedules altered schedule-controlled performance and the magnitude and direction of drug effects.

EXPERIMENT I
DRUG EFFECTS ON CONCURRENT FIXED-RATIO VARIABLE-INTERVAL PERFORMANCES

Method

Subjects

Six male pigeons served. Homing pigeons 51K, 52K, and 53K and White Carneaux pigeon B-3345 had responded under a variety of concurrent schedules before this experiment. White Carneaux pigeons B-277 and B-844 were experimentally naive. All pigeons were maintained at 80% of their free-feeding weights with continuous access to water and grit in the home cages.

Apparatus

Observations were made in sound-attenuating chambers, distant from programming and recording devices, with white noise present. Two Gerbrands pigeon keys, located on the front walls of each chamber, required a force of at least 0.1 N to record a response.

For Birds 51K, 52K, and 53K, the experimental space measured 37.0 by 61.0 by 26.5 cm. The keys, which could be transilluminated by 2-W white lights, were mounted 21.0 cm apart, 20.0 cm from the side wall, and 11.0 cm from the floor. Two openings, 7.0 by 5.0 cm, centered below each key 5.0 cm above the floor, provided access to grain for responding on each key. The openings could be illuminated by 2-W white lights. Also on the rear wall was a ventilation fan, an aperture for a closed-circuit television camera, and a 2-W white houselight in each corner. Experimental events were arranged with solid-state circuitry (K-Logic, Digital Equipment Corp).

For Birds B-277, B-844, and B-3345, the experimental space measured 28.0 by 29.0 by 30.0 cm. The keys, which could be transillinated by two 7-W red lights, were mounted 15.0 cm apart, 6.5 cm from the side wall, and 20.5 cm from the floor. A 4.0- by 6.0-cm opening below the key, cut 5.0 cm from the floor, provided access to grain. The opening could be illuminated by two 7-W white lights. In one rear corner, a 25-W white light provided general illumination, and in the other rear corner

a fan provided ventilation. Experimental events were arranged with electromechanical devices.

Procedure

Behavioral. Responding on the left key was associated with a schedule in which mixed grain was presented after a fixed number of responses (fixed ratio; FR). Responding on the right key was associated with a schedule in which grain followed the first response after varying time periods, with a given average time between grain presentations (variable interval; VI). The arithmetic VI schedule operated continuously during each session, except when grain was available for responding under that schedule. Keylights and houselights went off and the grain opening was illuminated when grain was presented. The first response on a key following responding on the other key initiated an interval during which delivery of grain was prevented. This interval, called the changeover delay (COD), reduces switching between schedules (Herrnstein, 1961).

Sessions were conducted at the same time, seven days a week with Birds 51K, 52K, and 53K. Access to grain during sessions lasted 2.5 sec and each session terminated after either 45 grain deliveries or 1 hr, whichever occurred first. Sessions were conducted at the same time, five days a week with Birds B-277, B-844, and B-3345. Grain was presented in the apparatus for 3.0 sec and each session was terminated after 50 food presentations or 1 hr.

Stability criteria. Stability was assessed by inspecting daily plots of overall response rates and the percentage of food deliveries obtained under each schedule. After at least 20 sessions, if increasing and decreasing trends were not evident during the last five sessions, performance was deemed stable. If trends were evident, additional sessions were conducted until five consecutive sessions occurred without trends. In all cases, this criterion was met by Session 30. These criteria were applied throughout this experiment, except with single schedule manipulations, as noted below.

Data calculations. A response on each key initiated separate timers, which stopped when a response was made on the alternate key. Local response rates under each schedule were computed by dividing the number of responses on a key by the number of minutes accumulated on the timer associated with that key. Overall response rates under each schedule were computed by dividing the number of responses emitted on each key by the total session time.

Schedule manipulations. The effects of drugs were studied on several concurrent FR VI schedules with FR requirements of 50 or 100 responses, with average VI durations of 1.5 or 4 min, and with COD durations of 1.5 or 30 sec. A 1.5-sec COD is within the range of values typically used in studies of concurrent schedules. However, with concurrent FR VI schedules, a 1.5-sec COD influences responding only under the VI schedule, because it takes longer than 1.5 sec to complete ratios of 50 and 100 responses. A 30-sec COD, on the other hand, can influence responding under both VI and FR schedules. The ratio requirement and the VI duration were varied to produce changes in relative responding under each schedule. For example, more time is spent responding under the FR 50 schedule than under the associated VI schedule, but the opposite is true with an FR 100 schedule (*cf.*

Table 1

Order and total number of sessions pigeons were exposed to each schedule.

Concurrent Schedule (all VIs in minutes)	*Number of Sessions*		
Experiment I	*51K*	*52K*	*53K*
FR 100, VI 4, 30-sec COD	96	99	96
FR 50, VI 4, 30-sec COD	55	66	56
FR 50, VI 4, 1.5-sec COD	69	85	82
	B-277	*B-844*	
FR 50, VI 1.5, 1.5-sec COD	119	119	
FR 50, VI 4, 1.5-sec COD	128	130	
FR 100, VI 4, 1.5-sec COD	40[a]	83	
	B-844	*B-3345*	
FR 100, VI 4, 1.5-sec COD[b]	10	—	
FR 100[c]	20	—	
VI 4[c]	25	—	
FR 50, VI 4, 1.5-sec COD[d]	22	23	
FR 50[c]	16	16	
VI 4[c]	21	22	
Experiment II	*B-882*	*B-890*	*B-958*
FR 50, FI 1.5, 1.5-sec COD	95	94	93
FR 50, FI 4, 1.5-sec COD	75	74	72
FR 50, FI 10, 1.5-sec COD	75	72	72

[a]Died during exposure to this schedule.

[b]This condition immediately followed exposure to the same schedule shown above.

[c]Single schedule in effect; key associated with other schedule was covered.

[d]Approximately six months elapsed between this condition and the previous one.

Bacotti, 1977). Drug effects also were assessed on single FR 100, FR 50, and VI 4-min schedules (the alternate key was covered) to determine whether increased responding under concurrent FR VI schedules resulted directly from the rate-enhancing effect of the drug on responding under a particular schedule, or indirectly from rate-decreasing effects of the drug on responding under the other schedule. Relatively few sessions were needed to obtain stable performance under these single schedules because the large changes in behavior that occurred in the first session did not vary much over subsequent sessions.

The exact sequence and number of sessions of exposure to each schedule are shown in Table 1. The number of sessions at each condition includes all sessions necessary to obtain stability before drug administration (20 to 30 sessions, except with single-schedule procedures) and all sessions during drug series before changing schedule conditions.

Pharmacological. Pentobarbital sodium and *d*-amphetamine sulfate were dissolved in 0.9% sodium chloride and injected into the breast muscle in a constant volume (1 ml/kg) on Tuesdays and Fridays. Each dose (total salt) was given twice in an irregular order immediately before starting sessions. Dose-effect curves for each drug were completed and replicated before changing drugs. For Birds 51K, 52K, and 53K, data collected on Mondays and Thursdays were averaged during each drug series and served as the nondrug control performance with which the effects of drugs were compared. For Birds B-277, B-844, and B-3345, performances on Thursdays were used to compute control rates.

Results

Control performance. Figures 1 and 2 summarize the effects of *d*-amphetamine and pentobarbital on responding under several *conc* FR VI schedules. Mean control (C) rates were calculated separately during the *d*-amphetamine and pentobarbital series. For all birds, control rates under the FR 50 schedule (open circles) were higher than rates under the VI 4-min schedule (filled circles) with a 1.5-sec COD in effect (Figure 1, bottom row; Figure 2, panels B, D, G, I). With a 30-sec COD (middle row, Figure 1), FR rates were also greater than VI rates for two pigeons. All birds exposed to the *conc* FR 100 VI 4-min schedule, regardless of COD, maintained higher overall rates under the VI schedule than under the FR schedule (Figure 1, top row; Figure 2, panels E, J). Under the *conc* FR 50 VI 1.5-min (1.5-sec COD) schedule, overall rates of B-277 were higher under the FR schedule than the VI schedule (A, F, Figure 2), but the opposite was true with B-844 (Figure 2, panels C, H). In general, with larger FR requirements (FR 100) the VI schedule maintained higher overall rates than the FR schedule, whereas with smaller FR requirements (FR 50) the opposite was true. Increases in overall VI response rates when FR requirements were increased have been reported in more detail elsewhere (Bacotti, 1977). In addition, higher rates were maintained by the FR 50 than by the FR 100 schedule, and higher rates were maintained by the VI 1.5-min than by the VI 4-min schedule. In several instances, control rates varied widely, as indicated by the ranges, but this variability was not systematically related to schedule conditions. Under all schedule parameters, responding under the FR schedule, once initiated, generally continued until food delivery. Responding under the VI schedules occurred before initiating the next ratio. With a 30-sec COD, responding on both schedules occurred in long sequences and, consequently, with fewer changeovers than with a 1.5-sec COD.

Drug effects on overall rates. Figure 1 shows dose-effect curves for both drugs under three different schedules (rows) for Birds 51K, 52K, and 53K (columns). The effects of pentobarbital and *d*-amphetamine on responding under the *conc* FR 100 VI 4-min (30-sec COD) schedule are shown in the top row. Note that on this schedule, FR control rates were lower than VI control rates. Most doses of *d*-amphetamine eliminated FR responding (broken lines, open circles), while 0.3 mg/kg and 1.0 mg/kg doses left unchanged or increased VI responding above control rates (broken lines, filled circles). Higher doses decreased VI responding. On the other hand, 5.6 mg/kg pentobarbital (solid lines, open circles) slightly increased FR responding above control rates for all pigeons, and 10 mg/kg greatly increased FR responding for Bird 51K. These same doses either decreased or did not affect VI responding (solid lines, filled circles).

The middle row of Figure 1 shows the effect of pentobarbital with the FR 50, rather than

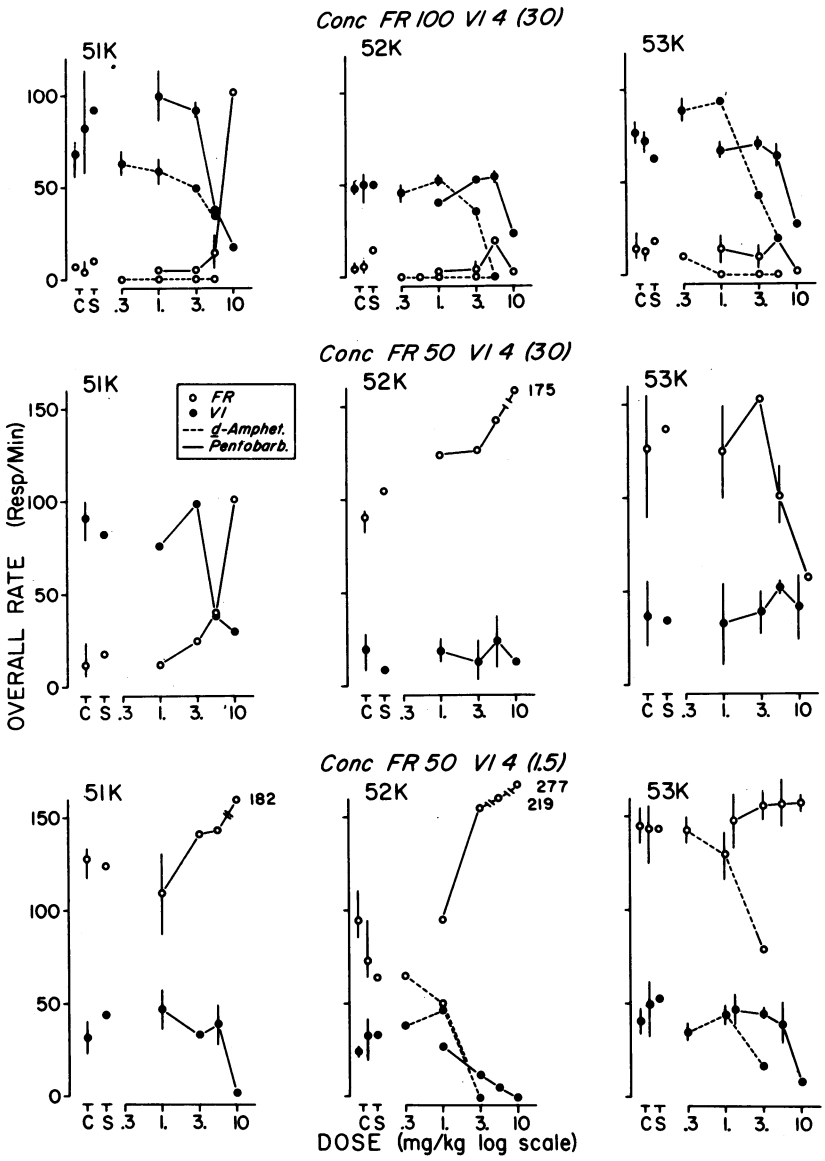

Fig. 1. Dose-effect curves for Birds 51K, 52K, and 53K under three concurrent schedules. Solid circles represent overall response rates under the VI schedule; open circles represent responding under the FR schedule. Broken lines are for doses of *d*-amphetamine and solid lines for doses of pentobarbital. Data points above *C* on the left are means of response rates on control days taken during the *d*-amphetamine series. Control rates for pentobarbital are shown next and then the rates for saline (S) administration. Ranges about the means (vertical lines) under drug are indicated only when there was an overlap with the range of control rates. Single points indicate either that the variability was encompassed within the data point or that response rates did not overlap the range of control rates. Two points from the pentobarbital series above 1.0 mg/kg in the bottom-right panel and the open circles above 10 mg/kg in the middle-right panel were shifted to the right to accommodate the overlap in ranges.

the FR 100 schedule, in effect (*conc* FR 50 VI 4-min, 30-sec COD). For Bird 51K, reducing the FR requirement did not affect control rates. By comparison, for Birds 52K and 53K, overall rates under the FR schedule were now higher than overall rates under the VI schedule, *i.e.*, with the decrease in FR requirement, VI responding decreased and FR responding increased. For Bird 51K, 5.6 mg/kg of pentobarbital, and for Bird 52K all doses, increased responding above control rates. These same doses left unchanged or de-

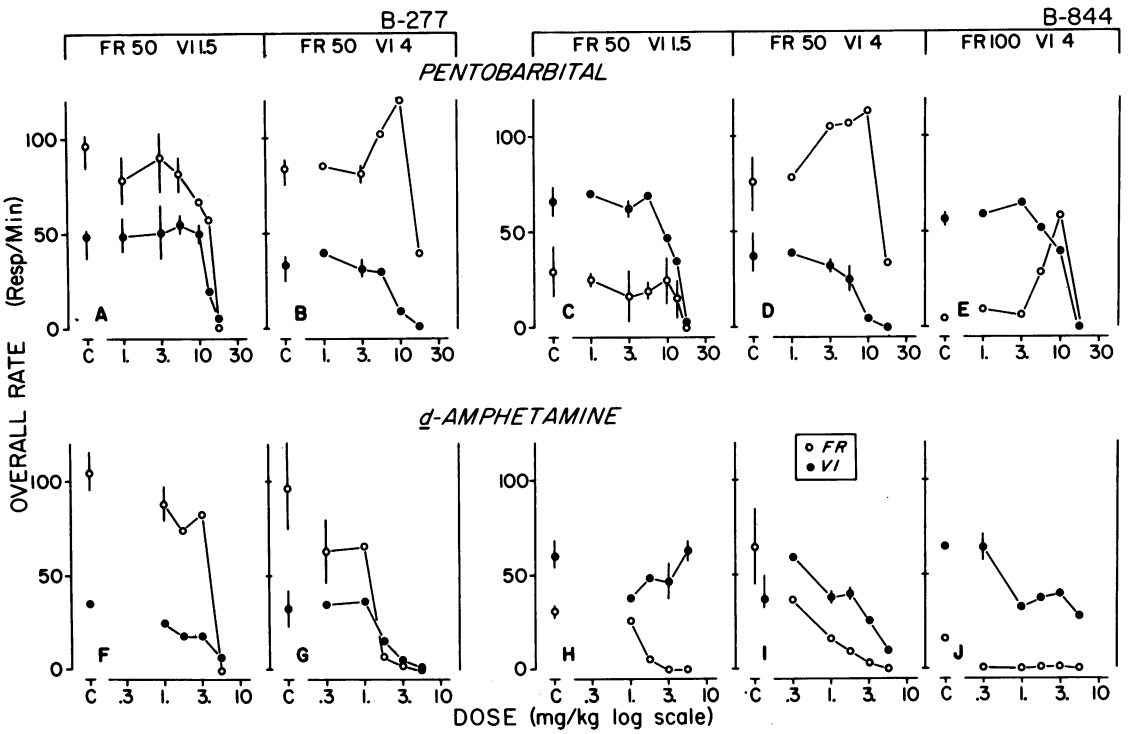

Fig. 2. Dose-effect curves for Birds B-277 and B-844. Overall rates under pentobarbital are shown in the top row and for amphetamine in the bottom row. Open circles indicate responding under the FR schedule and filled circles indicate responding under the VI schedule. Under all schedules, a 1.5-sec COD was in effect. Control points (C) for each drug series are shown to the left of each function. Vertical lines through control points show the range of the response rates comprising the mean. Ranges are also indicated for the mean of two determinations of drug whenever responding fell within the range of control rates. All points without ranges indicate either that the variability is encompassed within the data point or that response rates after each administration of that dose of drug did not overlap the range of control rates.

creased responding on the VI schedule. In spite of the large changes in control performance with Bird 53K, pentobarbital did not increase FR responding above control rates.

The effects of *d*-amphetamine and pentobarbital on responding with a 1.5-sec COD, rather than a 30-sec COD (*conc* FR 50 VI 4-min, 1.5-sec COD schedule), are illustrated in the bottom row of Figure 1. For Bird 51K, reducing the COD from 30 to 1.5 sec produced control rates similar to those of the other birds; for all subjects, control rates now were higher under the FR schedule than under the VI schedule. With the 1.5-sec COD, pentobarbital produced larger increases in responding under the FR schedule than previously observed with the 30-sec COD. For example, a broader range of doses (3.0 to 10 mg/kg) was effective in increasing FR responding in Bird 51K, while larger increases were associated with peak doses (5.6 to 10 mg/kg) for Bird 52K. For Bird 53K, doses of pentobarbital (5.6 to 10 mg/kg) that decreased FR responding with the 30-sec COD now left FR responding at control levels. In general, doses of pentobarbital that increased or did not affect FR responding decreased responding under the VI schedule. For example, a dose of 10 mg/kg pentobarbital produced the largest increase in FR responding above mean control rates, and also reduced responding under the VI schedule to near zero. On the other hand, *d*-amphetamine decreased FR responding of Bird 52K (0.3 to 1.0 mg/kg) and Bird 53K (1.0 mg/kg) at doses that increased or left VI responding unchanged.

Further comparison of the effects of pentobarbital and *d*-amphetamine with Birds B-277 and B-844 are illustrated in Figure 2. In all cases, the COD was 1.5 sec. With the *conc* FR 50 VI 1.5-min schedule (panels A and C), low doses of pentobarbital did not increase responding under the FR schedule (open circles)

and generally left VI rates unchanged (filled circles). Higher doses of pentobarbital (10 to 17 mg/kg) decreased responding under both schedules. It should be noted that these effects occurred in conjunction with different control performances. Bird B-277 responded at higher rates under the FR schedule and Bird B-844 at higher rates under the VI schedule. When the schedule was changed to *conc* FR 50 VI 4-min (panels B and D), pentobarbital increased FR responding of both birds at doses that decreased VI responding. These effects of pentobarbital under the *conc* FR 50 VI 4-min schedule with Birds B-277 and B-844 were similar to those obtained under the same schedule with Birds 51K, 52K, and 53K.

The effects of *d*-amphetamine also were related to the parameter of the VI schedule. With the *conc* FR 50 VI 1.5-min schedule, *d*-amphetamine generally decreased responding under both schedules (panels F and H). However, under the *conc* FR 50 VI 4-min schedule, lower doses of *d*-amphetamine (0.3 to 1.7 mg/kg) generally increased or did not affect responding under the VI schedule but decreased responding under the FR schedule (panels G and I).

When the FR requirement was increased from 50 to 100 responses (panels E and J), the effects of pentobarbital were similar to those obtained when the FR requirement was 50 responses, even though control rates now were higher under the VI schedule than the FR schedule. However, with the FR 100 schedule, 3.0 mg/kg was not an effective rate-increasing dose, whereas with the FR 50 schedule it was. All doses of *d*-amphetamine decreased responding under the FR 100 schedule, whereas the lowest dose did not decrease responding under the VI schedule.

Drug effects and local rates. Response rates in the concurrent schedules can be expressed in terms of time spent responding on a given key and its associated schedule (local rates), rather than with respect to the total session time (overall rates) as reported above. In the present study, local rates under the FR schedule always were higher than under the VI schedule. However, local FR and VI rates did not vary systematically as a function of changes in the parameters of the concurrent schedules, or of the administration of drugs. That drug effects were not manifested in terms of changes in local rates is illustrated in Figure 3, which is a cumulative record selected from the second administration of 10 mg/kg pentobarbital to 51K on the *conc* FR 100 VI 4-min (30-sec COD) schedule (rows 2 and 4). Also shown are control records from the day before administration of this dose of drug (rows 1 and 3). The FR control record (row 1) shows that one ratio was completed without interruption (note changeovers on the event pen), yielding a high local rate of responding and a low overall rate of responding. With 10 mg/kg pentobarbital (row 2), the local rate under the FR schedule remained high and essentially unchanged, but the overall rate increased markedly. The VI control record (row 3) shows that under the VI schedule, responding occurred throughout most of the session, whereas with drug (row 4) this time was substantially reduced. In spite of changes in overall rate, local rates of variable-interval responding under drug were similar to those during control sessions, but sequences of responding lasted for shorter time periods.

Figure 4 illustrates with cumulative records the effects of increasing doses of pentobarbital on local rates with a different schedule, *conc* FR 50 VI 4-min (1.5-sec COD). Records are from either the first or second administration of each dose to Bird B-844. A dose of 1.0 mg/kg left overall rates at control levels, while higher doses decreased responding under the VI schedule and increased responding under the FR schedule. However, local rates under the FR schedule did not increase systematically, even though the record shows fewer pauses before each ratio unit. These apparent pauses represent time when the pigeon had changed over to responding under the VI schedule. Thus, the influence of the drug was to decrease time spent responding under the VI schedule, rather than to increase local rates under the FR schedule.

Drug effects with single schedules. Overall control rates and rates under drug are shown in Table 2. When the key associated with the VI schedule was covered, rates under the single FR schedule were higher than previous rates on the concurrent schedule. Pentobarbital (10 mg/kg) further increased responding under the single FR schedules. When the key associated with the FR schedule was covered, control rates under the single VI 4-min schedule also increased above concurrent levels. Doses of *d*-amphetamine decreased or did not

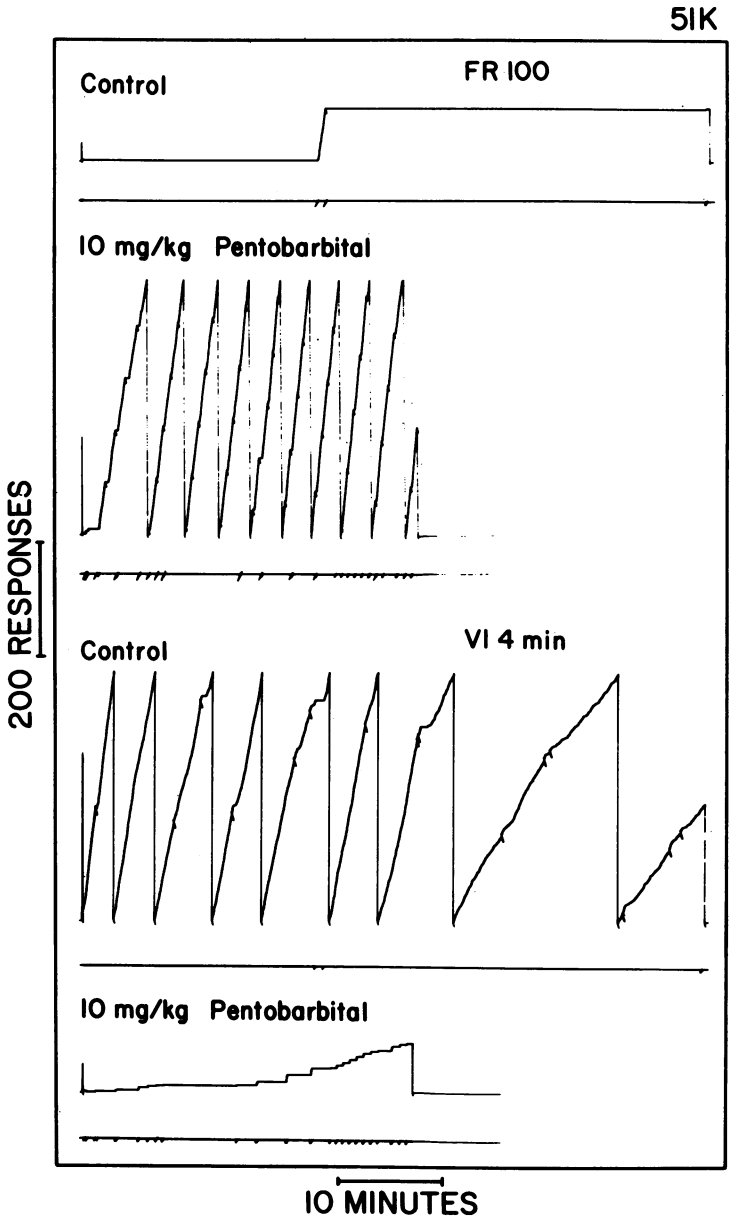

Fig. 3. Cumulative response records from Bird 51K under a *conc* FR 100 VI 4-min (30-sec COD) schedule. Control performances under each schedule are from the session before administration of 10 mg/kg pentobarbital. The top two records show responding under the FR schedule and the bottom two records responding under the VI schedule. In these and subsequent cumulative records, deflections of the event pen indicate changeover responses and deflections of the response pen indicate food deliveries.

affect response rates under the isolated VI 4-min schedule.

These effects are illustrated in Figure 5 with cumulative records from B-844. The top records of Figure 5 show control rates during the last session under the *conc* FR 100 VI 4-min (1.5-sec COD) schedule. Rates under the VI 4-min schedule (A) were high and constant, while overall rates under the FR 100 schedule (B) were low, with completion of just one ratio requirement. During the first session in which only the key associated with the FR schedule was available (C), there was a substantial increase in overall rates that was maintained dur-

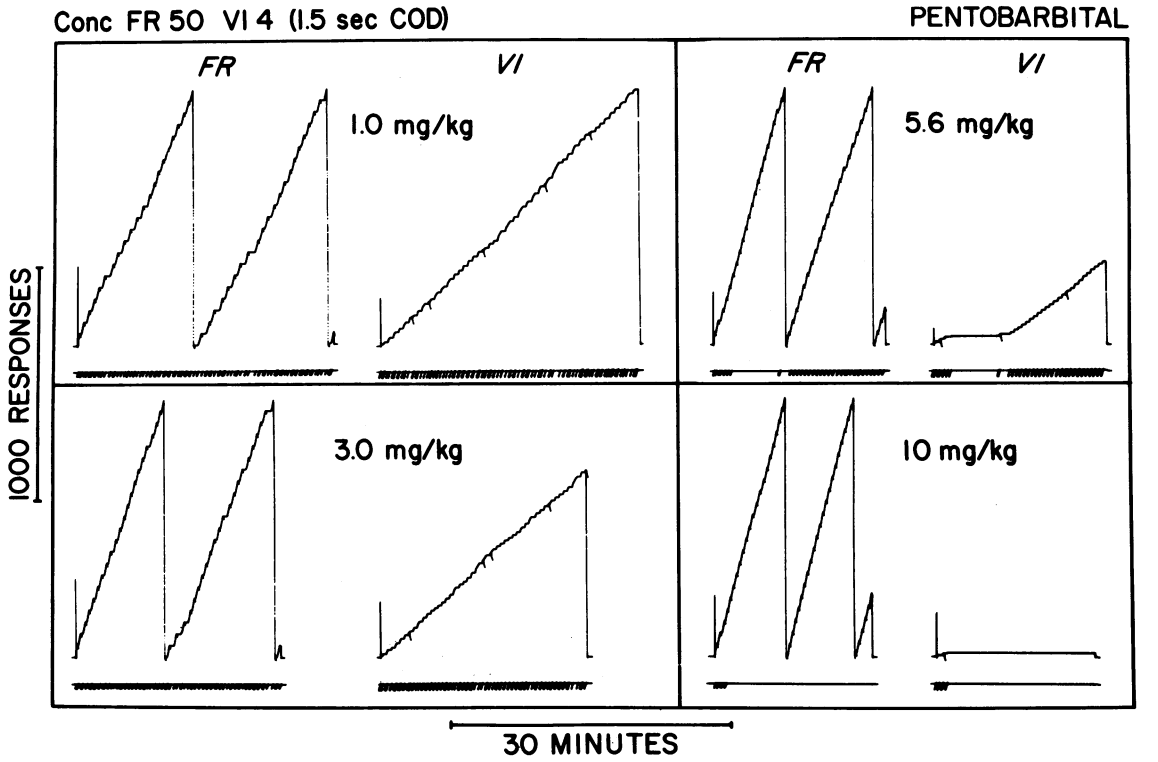

Fig. 4. Cumulative response records from Bird B-844 illustrating the effect of four doses of pentobarbital on responding under a *conc* FR 50 VI 4-min (1.5-sec COD) schedule.

ing succeeding sessions. The bottom record (D) shows further increases in FR responding after the first administration of 10 mg/kg pentobarbital.

Discussion

These results show that the effects of drugs on responding under a particular schedule of

Table 2

Responses per minute under FR and VI schedule before and after keys were covered. Ranges of control rates are shown in parentheses. Rates from two administrations of each drug are also shown. Control rates are means of last three sessions.

	B-844		*B-3345*		*B-844*	
	FR 50	*VI 4-min*	*FR 50*	*VI 4-min*	*FR 100*	*VI 4-min*
Concurrent (control)	77 (74-80)	37 (35-40)	83 (77-98)	25 (22-26)	5 (2-7)	56 (53-60)
FR alone (control)	92 (86-100)	—	126 (113-130)	—	62 (57-67)	—
10 mg/kg pentobarb.	141	—	145	—	133	—
	131	—	142	—	133	—
VI alone (control)	—	68 (65-73)	—	45 (41-51)	—	61 (59-65)
0.3 mg/kg *d*-amphet.	—	70	—	34	—	54
	—	70	—	49	—	57
1.0 mg/kg *d*-amphet.	—	59	—	45	—	41
	—	56	—	37	—	54

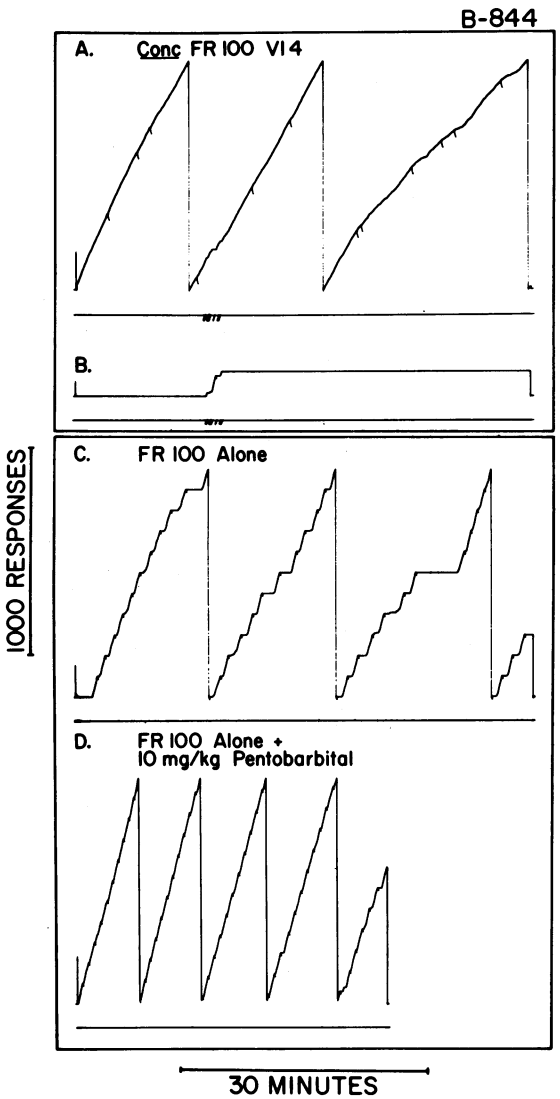

Fig. 5. Cumulative response records from Bird B-844 showing the effect of covering the key associated with the VI schedule. Top records show responding under each of the concurrent schedules: VI 4-min (A) and FR 100 (B). Responding under the FR schedule when the VI schedule and key were removed is shown in record *C*. Record *D* shows the effect of administration of pentobarbital on FR responding when the VI schedule and key were removed.

reinforcement depend both on parameters of that schedule and also on parameters of concurrently available schedules. For example, pentobarbital was most effective in increasing FR responding under the *conc* FR 50 VI 4-min (1.5-sec COD) schedule and was less effective or did not increase FR responding under concurrent schedules in which the COD was longer, the VI was shorter, or the FR was larger. Further, when the opportunity to respond under one of the two schedules was removed by covering the key associated with that schedule, responding under the remaining schedule increased. Pentobarbital increased responding under the single FR schedule but *d*-amphetamine did not affect or decrease responding under the single VI schedule. Thus, the rate-increasing effects of pentobarbital on FR responding under the concurrent schedule probably resulted both from a direct rate-enhancement under the FR schedule, and indirectly, from decreases in responding under the VI schedule. On the other hand, the marginal increases in responding under the VI schedule with *d*-amphetamine probably resulted indirectly from a reduction in responding under the FR schedule, and not directly from increases under the interval schedule.

Overall and local rates of responding in the absence of drug were not reliable predictors of response-rate changes under drug. Changes in the VI, FR, and COD parameters, however, produced changes in time spent responding, as well as in rate. When the interreinforcement duration of the VI schedule was increased, or the FR requirement was decreased, time responding under the VI schedule decreased and time responding under the FR schedule increased. Thus, changing schedule parameters influenced both the behavior controlled by a particular schedule and the relation between that behavior and other schedule-controlled behavior. Since the effects of drugs also changed in accordance with changes in schedule parameters, these findings suggest that such drug effects depend on control by a particular schedule, and also on the control of behavior by that schedule relative to other schedule-controlled responding.

EXPERIMENT II
DRUG EFFECTS ON CONCURRENT FIXED-RATIO FIXED-INTERVAL PERFORMANCES

The generality of the findings of Experiment I was extended by studying the effects of *d*-amphetamine and pentobarbital under several parameters of a fixed-interval schedule arranged concurrently with a fixed-ratio schedule.

METHOD

Subjects and Apparatus

Three experimentally naive, male White Carneaux pigeons, B-882, B-890, B-958, were maintained at 80% of their free-feeding weights. Grit and water were continuously available in the home cages. The experimental chamber and apparatus were the same as that described for Bird B-844 in Experiment I.

Procedure

Behavioral. Pigeons were trained to peck each key by reinforcing successive approximations and then exposed to concurrent fixed-ratio fixed-interval schedules of food presentation (*conc* FR FI). Under this schedule, mixed grain (3 sec access) was presented following each fiftieth response on the left key (FR) and for the first response on the right key after a fixed time (FI). The FI schedule was, in successive conditions, either 1.5 min, 4 min, or 10 min, timed from the completion of grain presentation under that schedule. Each change in responding from one key to the other initiated a 1.5-sec COD. The stability criteria were the same as described for Experiment I. Table 1 shows the number of sessions and the order of exposure to conditions.

Keys were transilluminated red and a houselight illuminated the chamber throughout each session, except during grain delivery when these lights were turned off and the lights above the opening for grain were turned on. Sessions were conducted at the same time, five days a week, and terminated after 50 food deliveries or 1 hr.

Pharmacological. Drug administration procedures were the same as described for Bird B-844 in Experiment I.

RESULTS

Control performance. The effects of pentobarbital and *d*-amphetamine on responding under several *conc* FR FI schedules are summarized in Figures 6 and 7. Mean control (C) rates were calculated separately for each drug series and are shown with ranges at the left of each dose-effect curve. The figures show that for the two longer FIs, 4 min and 10 min (columns 2 and 3), FR rates exceeded FI rates in all control comparisons. With the shortest FI, 1.5 min (column 1), performances were not uniform across subjects, with FI rates higher for one (B-882), lower for another (B-958), and no difference in the remaining case (B-890). Figures 6 and 7 also show that changes in the duration of the FI had systematic effects in two of three birds (B-882 and B-890), with FR rates tending to increase and FI rates tending to decrease as the interval was increased from 1.5 sec to 4 min and 10 min.

Generally, responding on the key associated with the FR schedule was maintained at a high, steady rate until food delivery. Changeovers to the key associated with the FI schedule occurred after most food deliveries under the FR schedule. Responding on the key associated with the FI schedule also tended to occur in bursts of high rates, followed by periods of no responding, during which responding occurred under the FR schedule (*cf.* control records in Figure 8).

Drug effects on overall rates. Dose-effect curves for pentobarbital under the three schedules are presented in Figure 6. In all cases, intermediate doses of pentobarbital increased overall rates under the FR schedule. The extent of these increases was related to the parameter of the FI schedule; the larger the duration of the FI, the larger the increases in FR responding under drug.

The effects of pentobarbital on responding under the FI schedule also differed depending on the FI duration. The intermediate doses of pentobarbital tended to increase overall rates under the FI 1.5-min schedule, but not under the FI 4-min and FI 10-min schedules. Those doses of pentobarbital that increased responding under the FR schedule, however, did not increase (and in some cases decreased) responding under the FI schedule.

The effects of *d*-amphetamine on overall response rates under each schedule are presented in Figure 7. Increasing doses of *d*-amphetamine systematically decreased responding under the FR schedule, and intermediate doses increased responding under the FI schedule for two of the three birds, B-882 and B-958. These effects of drug on FI responding were determined by the schedule. Under the FI 1.5-min schedule, *d*-amphetamine generally decreased response rates, whereas under the FI 4-min and FI 10-min schedules, *d*-amphetamine increased or maintained response rates of these two birds over a broad range of doses.

Drug effects on local rates. The cumulative records in Figure 8 were selected from Bird

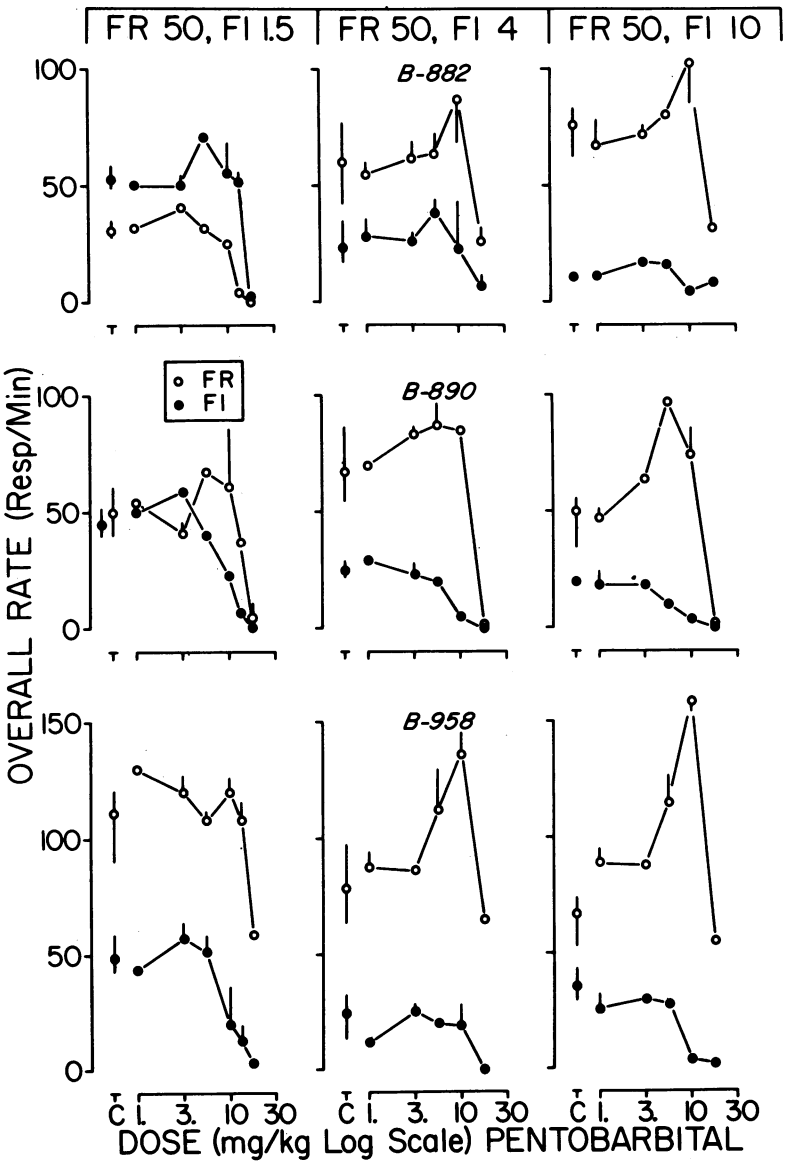

Fig. 6. Dose-effect curves for Birds B-882, B-890, and B-958 showing the effects of pentobarbital under three different concurrent schedules. Response rates under the FR schedule are indicated with open circles; response rates under the FI schedule are indicated with filled circles. Control rates (C) with ranges (vertical lines) are shown to the left of each function. Vertical lines also show range of response rates from multiple determinations of the same dose of drug. Ranges are illustrated only in one direction, since variability is symmetrical.

B-958 to illustrate major effects of drugs on response rates. The schedule was *conc* FR 50 FI 10-min (1.5-sec COD). Pentobarbital (bottom records) increased local FR rates above control levels (top records), but unlike the effect of pentobarbital on overall rates, the same doses also generally increased local rates under the FI schedule. Some doses of pentobarbital that decreased overall rates under the FI schedule sometimes increased local rates under that schedule. Such increases, however, reflect small bursts of responses emitted in rapid sequence (see, for example, effect of 10 mg/kg pentobarbital on FI responding) and do not reliably reflect major drug effects.

In contrast to the effects of pentobarbital, doses of *d*-amphetamine (middle records) decreased local rates of responding under each

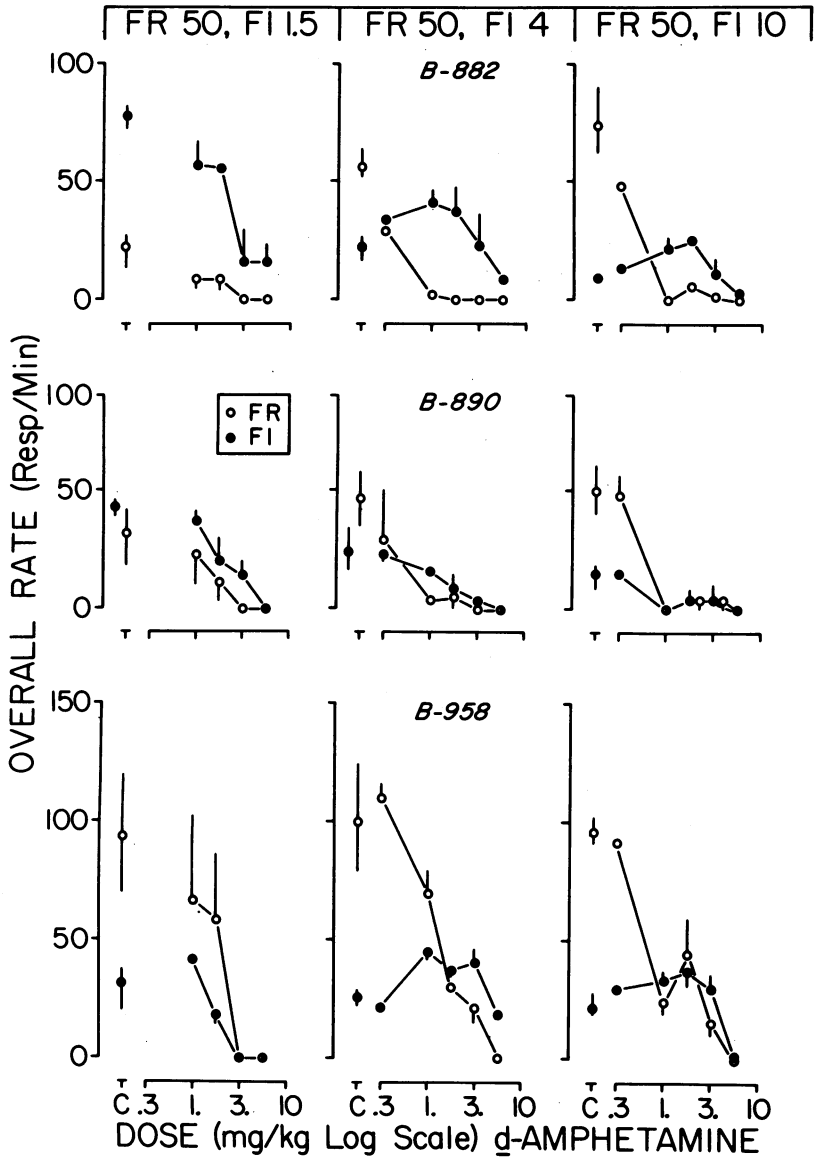

Fig. 7. Dose-effect curves for Birds B-882, B-890, and B-958 showing the effects of *d*-amphetamine under three concurrent schedules. Open circles illustrate responding under the FR schedule and filled circles illustrate responding under the FI schedule. Control rates (C) with ranges (vertical lines) are shown at the left of each function. Ranges are shown in one direction on drug points, since variability is symmetrical about the mean. In the right middle dose-effect curve, two FR points (1.7 to 3 mg/kg) were moved to the right to accommodate the variability measure.

schedule. These data indicate that differences in the rate-increasing effects of pentobarbital and *d*-amphetamine depended not only on the schedule but also on the factors producing those increases. Specifically, increases in overall FR rates with pentobarbital resulted from both decreased responding under the FI schedule and increased local rates under the FR schedule. On the other hand, increases in overall FI rates resulted from decreased time spent responding under the FR schedule, but not from increased local rates under the FI schedule.

Figure 8 also shows that some doses of pentobarbital (bottom records) decreased overall responding on the FI schedule below control

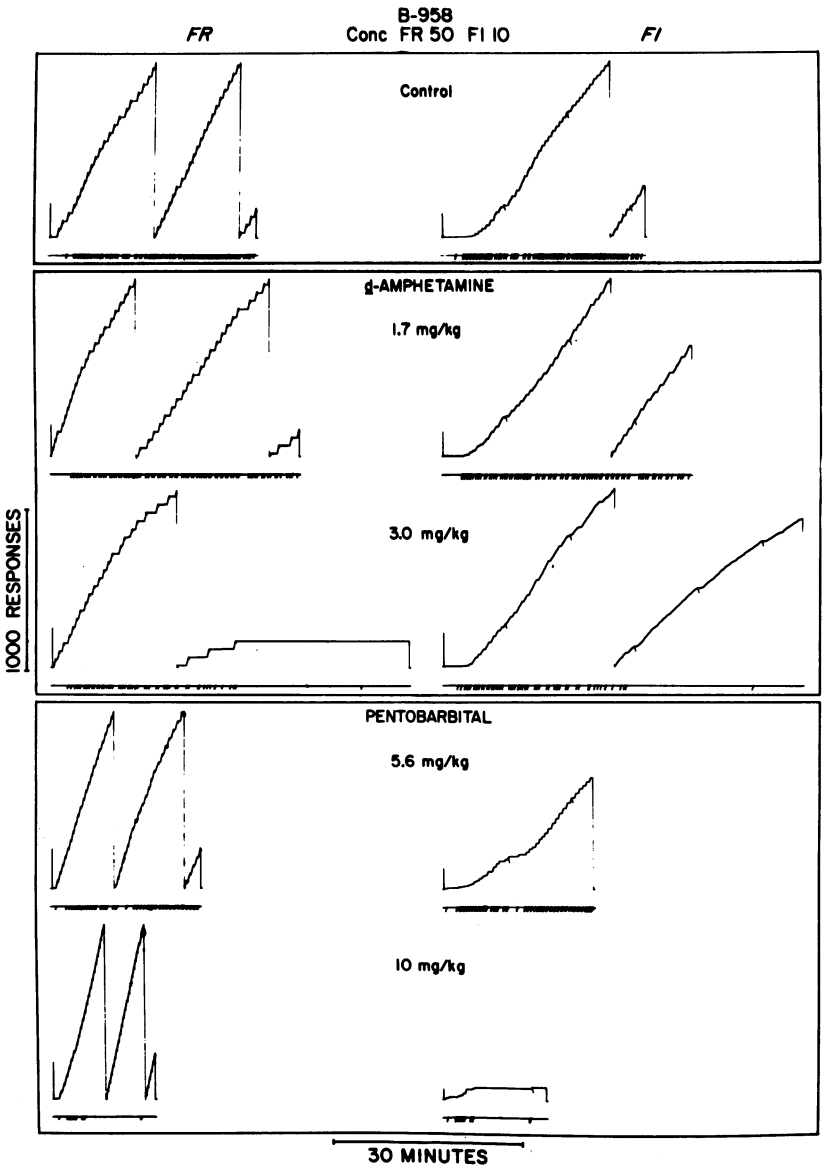

Fig. 8. Cumulative response records from Bird B-958 illustrating major effects of drugs on responding under a *conc* FR 50 FI 10-min schedule. These records are from complete sessions either without drug (control) or with doses of *d*-amphetamine (1.7 to 3.0 mg/kg) and pentobarbital (5.6 to 10 mg/kg). Responding under the FR schedule is shown on the left, responding under the FI schedule on the right.

levels (top records) and increased responding on the FR schedule. Doses of *d*-amphetamine (middle records) increased overall responding under the FI schedule while decreasing or eliminating responding under the FR schedule. Changeover responses (shown as deflections on the event pen) also decreased with increasing doses of both drugs. It should be noted that sessions terminated with time under *d*-amphetamine because of the decrease in frequency of food presentation under the FR schedule, but terminated with number of food deliveries under pentobarbital.

Table 3 shows changes in the number of responses, the time spent responding, and the number of food deliveries under the FI schedule relative to the FR schedule. These data are presented as relative ratios (FI/FI+FR) during each drug series. Control (C) ratios from each series show a general tendency to decrease with

increases in the FI parameter, indicating greater relative control of responding by the FR schedule. Increasing doses of *d*-amphetamine resulted in increased control of responding by the FI schedule, as indicated by the increases in the ratios of responses, time, and food deliveries. On the other hand, increasing doses of pentobarbital resulted in increased control of responding by the FR schedule, as indicated by decreases in the performance ratios. An exception to this general trend may be noted under the *conc* FR 50 FI 1.5-min schedule with Bird B-882. Note that some extreme values at higher doses of each drug may reflect the influence of very little responding under one schedule.

Discussion

The results of Experiment II with *conc* FR FI schedules support and extend the findings obtained with *conc* FR VI schedules in Experiment I. First, *d*-amphetamine increased overall responding under the FI schedule at doses that decreased responding under the FR schedule, and pentobarbital increased overall responding under the FR schedule at doses that decreased responding under the FI schedule. Second, these effects were related to the parameter of the FI schedule. Increases under the FR schedule with pentobarbital and increases in responding with *d*-amphetamine under the FI schedule were generally greater under the longer FI schedule. Thus, the effects of pentobarbital were related not only to the FR schedule but also to the parameters of the schedule arranged concurrently. Third, pentobarbital increased overall rates under the FR schedule both directly by increasing local rates under that schedule and indirectly by decreasing overall rates under the FI schedule. *d*-Amphetamine, however, decreased local rates under each schedule, suggesting that increased overall rates under the FI schedule resulted indirectly from decreased overall rates under the FR schedule. As shown with performance ratios, changes in overall rates with *d*-amphetamine occurred because a greater proportion of the session was spent responding under the FI schedule, and not because responses were emitted more rapidly.

Although the schedule of reinforcement is an apparently good predictor of the differential effects of drugs, the relation between drug effect and schedule type must be qualified. For example, the shorter FI schedule controlled response patterns and response rates that were similar to those controlled by the FR schedule. Drug effects tended to become more similar under each schedule when control performances were more similar. Thus, in addition to the apparent specificity between drug effects and schedule type, other factors related to the interaction between concurrently controlled performances may be determinants of the effects of drug.

GENERAL DISCUSSION

With certain schedule parameters, effects of drugs on responding under concurrent schedules are similar to those under single and multiple schedules. Previous experiments have shown that pentobarbital increases responding under single FR schedules (Dews, 1955; Waller and Morse, 1963; Weiss and Gott, 1972), and that to a lesser extent, barbiturates increase responding under FI and VI schedules (Kelleher and Morse, 1968). Amphetamines, on the other hand, usually decrease FR responding at doses that markedly increase FI responding (Dews, 1958*a;* Kelleher and Morse, 1968; McMillan, 1968, 1969; Smith, 1964). However, increases in responding under VI schedules with amphetamines are marginal (Dews, 1958*a*), if they occur at all (*cf.* Sanger and Blackman, 1976*b*). Such effects were obtained in the present study when FR schedules were arranged concurrently with FI and VI schedules. For example, pentobarbital increased responding under FR schedules at doses that reduced or eliminated responding under FI and VI schedules. Amphetamine, on the other hand, slightly increased or left unchanged response rates under FI and VI schedules at doses that decreased FR responding.

In a previous study of *conc* VI VI performances, Todorov *et al.* (1972) found that local response rates were not increased by *d*-amphetamine. However, the percentage of all responses emitted on the shorter VI schedule increased with dose of drug, suggesting that changes in overall rates did occur. As shown in the present study, local rates are influenced greatly by the number of distributions of a few responses, and do not reflect large changes in performance that can be observed with other measures, such as overall rates. This outcome seems a consequence of the particular time base

Table 3

Performance ratios (FI/FI + FR). Control (C) data are means and ranges obtained during each drug series. Each proportion under drug is the mean from two administrations. Drug ranges show variability across all doses in a given series.

		d-*Amphetamine*								
		B-882			*B-890*			*B-958*		
Schedule	*Dose*	*Resp.*	*Time*	*Food*	*Resp.*	*Time*	*Food*	*Resp.*	*Time*	*Food*
	C	0.76	0.77	0.59	0.56	0.71	0.49	0.33	0.40	0.29
	range	0.67-0.87	0.66-0.86	0.54-0.72	0.49-0.68	0.69-0.72	0.42-0.62	0.22-0.44	0.30-0.50	0.18-0.40
	1.0	0.88	0.89	0.82	0.65	0.79	0.61	0.44	0.58	0.36
Conc FR 50	1.7	0.88	0.86	0.83	0.79	0.80	0.79	0.27	0.34	0.34
FI 1.5-min	3.0	0.90	0.78	1.0	1.0	0.97	1.0	No responding		
	5.6	1.0	0.95	1.0	1.0	0.86	1.0	No responding		
	drug range	0.80-1.0	0.76-0.98	0.72-1.0	0.54-1.0	0.73-0.98	0.48-1.0	0.20-0.60	0.22-0.69	0.22-0.50
	C	0.29	0.43	0.16	0.35	0.60	0.20	0.18	0.30	0.10
	range	0.22-0.35	0.36-0.48	0.14-0.16	0.21-0.45	0.51-0.70	0.16-0.24	0.15-0.26	0.25-0.52	0.08-0.10
	0.3	0.53	0.64	0.28	0.63	0.65	0.55	0.16	0.24	0.09
Conc FR 50	1.0	0.98	0.96	0.96	0.80	0.94	0.75	0.40	0.50	0.13
FI 4-min	1.7	0.99	0.96	1.0	0.79	0.94	0.77	0.64	0.76	0.27
	3.0	0.99	0.89	1.0	0.94	0.97	1.0	0.70	0.85	0.42
	5.6	1.0	0.95	1.0	1.0	0.96	1.0	0.95	0.98	0.93
	drug range	0.50-1.0	0.63-0.97	0.28-1.0	0.31-1.0	0.54-0.98	0.16-1.0	0.15-0.95	0.24-0.98	0.08-0.44
	C	0.10	0.24	0.05	0.22	0.44	0.08	0.20	0.26	0.04
	range	0.09-0.12	0.18-0.33	0.04-0.06	0.11-0.26	0.34-0.50	0.06-0.08	0.17-0.27	0.19-0.32	0.04-0.04
	0.3	0.20	0.37	0.08	0.25	0.50	0.09	0.20	0.30	0.04
Conc FR 50	1.0	0.99	0.96	1.0	1.0	0.95	1.0	0.58	0.77	0.16
FI 10-min	1.7	0.81	0.90	0.44	1.0	0.95	1.0	0.54	0.66	0.10
	3.0	0.89	0.94	0.75	1.0	0.87	1.0	0.66	0.86	0.23
	5.6	1.0	0.92	1.0	1.0	0.90	1.0	0.89	0.98	1.0
	drug range	0.18-1.0	0.36-0.98	0.08-1.0	0.2-1.0	0.42-0.96	0.08-1.0	0.22-0.98	0.28-0.98	0.04-1.0
		Pentobarbital								
	C	0.61	0.62	0.50	0.46	0.61	0.34	0.31	0.42	0.21
	range	0.54-0.66	0.54-0.70	0.44-0.54	0.31-0.57	0.52-0.70	0.32-0.44	0.26-0.40	0.39-0.48	0.20-0.26
	1.0	0.62	0.63	0.50	0.48	0.60	0.36	0.25	0.34	0.20
	3.0	0.55	0.56	0.44	0.55	0.68	0.44	0.32	0.41	0.20
Conc FR 50	5.6	0.68	0.71	0.49	0.37	0.48	0.30	0.33	0.39	0.22
FI 1.5-min	10.0	0.78	0.74	0.62	0.30	0.40	0.29	0.13	0.17	0.12
	13.0	0.92	0.76	0.83	0.16	0.19	0.23	0.10	0.15	0.12
	17.0	0.97	0.88	1.0	0.08	0.03	0.25	0.06	0.05	0.06
	drug range	0.52-0.97	0.52-0.88	0.42-1.0	0.08-0.63	0.02-0.70	0.16-0.46	0.04-0.38	0.05-0.44	0.06-0.20
	C	0.26	0.40	0.15	0.28	0.42	0.15	0.26	0.36	0.12
	range	0.18-0.45	0.29-0.58	0.12-0.22	0.21-0.35	0.39-0.60	0.10-0.18	0.12-0.44	0.22-0.55	0.10-0.16
	1.0	0.33	0.46	0.17	0.29	0.48	0.14	0.12	0.26	0.11
	3.0	0.30	0.39	0.15	0.22	0.40	0.12	0.22	0.32	0.11
Conc FR 50	5.6	0.38	0.44	0.15	0.19	0.37	0.11	0.16	0.21	0.08
FI 4-min	10.0	0.22	0.27	0.09	0.06	0.15	0.04	0.12	0.15	0.04
	17.0	0.22	0.10	0.10	—	—	—	0.01	0.03	0.02
	drug range	0.04-0.44	0.90-0.52	0.04-0.18	0-0.29	0-0.49	0-0.14	0-0.24	0-0.35	0-0.12
	C	0.13	0.30	0.05	0.29	0.52	0.08	0.35	0.45	0.06
	range	0.08-0.16	0.24-0.36	0.04-0.06	0.24-0.32	0.47-0.55	0.08-0.10	0.30-0.39	0.39-0.48	0.06-0.08
	1.0	0.15	0.30	0.06	0.27	0.53	0.09	0.22	0.30	0.04
	3.0	0.16	0.33	0.06	0.13	0.44	0.07	0.26	0.31	0.04
Conc FR 50	5.6	0.16	0.28	0.04	0.10	0.20	0.04	0.19	0.42	0.03
FI 10-min	10.0	0.04	0.05	0.03	0.04	0.06	—	0.02	0.07	0.02
	17.0	0.19	0.43	0.07	0.03	0.01	—	0.11	0.11	0.04
	drug range	0.04-0.23	0.05-0.62	0.02-0.08	0.01-0.32	0.01-0.54	0-0.10	0.01-0.28	0.01-0.36	0-0.04

used to calculate local rates in concurrent schedules (*i.e.*, time spent responding on a given schedule), which leads to values falling somewhere between complete specification of responding in terms of interresponse times and molar descriptions in terms of rates based on total available time to respond (overall rates). These considerations argue against the utility of local rates in characterizing performances on concurrent schedules of reinforcement.

The effects of pentobarbital in the present study depended not only on parameters of the FR schedule but also on the parameter of the schedule that was arranged concurrently. Specifically, pentobarbital increased responding under the FR 50 schedule with concurrent VI 4-min, FI 4-min, and FI 10-min schedules, but not with VI 1.5-min or FI 1.5-min schedules. Thus, the behavioral effects exerted by one schedule were of major importance in determining the effect of drug under another schedule. This influence of one schedule on the effects of drugs on another was most apparent in the present study with pentobarbital, but has been demonstrated also with *d*-amphetamine in a multiple avoidance-punishment schedule (McKearney and Barrett, 1975).

The present results showed that patterns of responding under the VI and FI schedules were influenced by concurrently arranged FR schedules. In the concurrent schedules, responding under the VI and FI schedules often resembled the "break-run" pattern typically seen with single FR schedules, rather than the steady rates generally found with single VI schedules or the positive acceleration found with single FI schedules. A changeover to responding under the VI and FI schedules usually occurred during pause periods under the FR schedule. Pentobarbital reduced the FR pause time and consequently the time spent responding under the interval schedules, producing increases in the time spent responding and the overall rates under the FR schedule. However, as shown with single FR schedules, pentobarbital reduced pauses whether or not that time was allocated to responding under other schedules (Experiment I).

Although some of the effects of amphetamines and barbiturates frequently have been attributed to predrug control rates (Dews, 1958*b*; Kelleher and Morse, 1968; Sanger and Blackman, 1976*a*), such effects were not observed in the present study. Rather, in several cases it was apparent that drug effects depended on the particular schedule, regardless of the overall rate of responding. For example, pentobarbital increased responding under the FR schedule whether or not overall rates were higher under that schedule than under the VI 4-min schedule. Overall control rates, therefore, do not provide a systematic description of the conditions under which pentobarbital and *d*-amphetamine had particular effects.

In general, increased response rates associated with pentobarbital were enhanced by decreasing the FR requirement, by decreasing the COD, and by increasing the parameter of the interval schedule. Changes in any one of these parameters increased control by the FR schedule, as indicated by an increase in the proportion of the total session time spent responding under the FR schedule. Thus, the more that responding was controlled by the FR schedule, the more effective was pentobarbital in increasing responding. For example, shortening the reinforcement intervals under the VI and FI schedules lessened control by the concurrently arranged FR schedule and also reduced the influences of pentobarbital on FR responding. Such findings also suggest that some effects of drugs on concurrent performances may be determined by the proportion of responding controlled by one schedule relative to responding controlled by other schedules.

Recent investigations have emphasized the importance of historic and current environmental factors in determining the effects of drugs. The present study makes the important point that the effects of drugs on behavior depend not only on the reinforcement schedule controlling that behavior, but also on factors controlling other concurrent behaviors. Changing the parameters of a schedule controlling one behavior may affect behaviors that are performed concurrently and alter the effects of drugs on both behaviors. Thus, a more complete characterization of the behavioral effects of drugs will require a more complete understanding of situations in which several behaviors occur, and of situations where schedule parameters vary.

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